Northern States Power Company

Prairie Island Nuclear Generating Plant

1717 Wakonade Dr. East
Welch, Minnesota 55089

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U S Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Docket Nos.50-282 License Nos. DPR-42
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Response to NRC Request For Additional Information Regarding Application of F* Steam Generator Tube Repair Criteria

By letter dated February 13, 1997, the NRC Staff requested additional information regarding the application of the F* steam generator tube repair criteria in order to determine the acceptability for continued service for tubes previously repaired by rerolling. The attached information is provided in response to that Request for Additional Information. The attached response is based on the results of NSP's evaluation of the steam generator tube in situ pressure tests and eddy current examination results obtained during the current Prairie Island Unit 2 refueling outage.

The February 13, 1997 letter also requested additional information regarding our October 17, 1996 License Amendment Request which requested approval of the Elevated F* steam generator repair criteria. A response to the questions related to the Elevated F* License Amendment Request will be provided at a later date.

In this letter we have made no new NRC commitments. Please contact Gene Eckholt (612-388-1121) if you have any questions related to the attached responses.

Joel P Sorensen
Plant Manager
Prairie Island Nuclear Generating Plant

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c: Regional Administrator - Region III, NRC
Senior Resident Inspector, NRC
NRR Project Manager, NRC
J E Silberg

Attachment: Response to February 13, 1997 NRC Request For Additional Information.

ATTACHMENT 1

Response to February 13, 1997 NRC Request For Additional Information

The following information is provided in response to the Request for Additional Information Regarding Application of F* and EF* Steam Generator Tube Repair Criteria dated February 13, 1997 received from the NRC Staff regarding the application of the F* steam generator tube repair criteria at Prairie Island:

RESPONSE TO NRC STAFF QUESTIONS

Question 1.a:

Provide an assessment of the rerolled F* tubes that experienced leakage during the secondary-side hydrostatic testing completed during the 1997 Unit 2 refueling outage. The assessment should address the issues identified in the action plan included in the document "Prairie Island Unit 2 9701 S/G Inspection Results," dated February 3, 1997. Also summarize the scope and results of the planned in-situ pressure testing. Demonstrate that the measured leakage is bounded by the leakage assessments in the F* license amendment request. Discuss the changes, if any, made to the reroll acceptance criteria to identify F* tubes that are rerolled into hard packed crevices.

Response:

Background

The F* criterion was authorized for use at Prairie Island by License Amendments 118 for Unit 1 and 111 for Unit 2, dated May 15, 1995 and implemented under Modification 95L486. The F* criterion in combination with an additional roll expansion (F* reroll) was applied to the tubesheet region below the centerline of the 21 inch thick tubesheet. The ABB Combustion Engineering process was used for the additional roll expansion.[1] There are currently 6 tubes in service in Unit 1 and there were 401 tubes in service in Unit 2 during the previous cycle (Cycle 17) using additional roll expansion and the F* criterion. There will be 629 F* rerolls in service for Unit 2 following this outage with 418 in 21 steam generator and 211 in 22 steam generator.

Steam generator tubes repaired in May 1995 by adding an additional roll expansion (F* reroll) in the tubesheet region (first application of F*) and by applying the F* repair criteria were inspected during the Unit 2 January 1997 refueling outage. The inspection identified twelve steam generator tubes repaired by the F* reroll process in May of 1995 that had leakage or seepage past the F* reroll and through the roll transition zone cracks. These F* reroll repairs had been in service for one cycle. Primary to secondary side leakage during the cycle had increased slowly to a range of 2 to 4 gallons per day total leakage during the operating cycle from July 4, 1995

through January 24, 1997. Although the additional F* reroll expansion area was expected to be nearly leak tight, it is obvious that in some cases due to sludge content, tube characteristics or tubesheet bore hole abnormalities, the F* reroll joint may not be leak tight even though the F* reroll meets process acceptance criteria.

Evaluation of the post F* rerolling eddy current examination (ECT) data showed that the indications of stress corrosion cracking at the original equipment manufacturer's (OEM) roll transition zones with leaking cracks changed during the F* rerolling process and were probably the source of the minor primary to secondary side leakage identified early in the previous cycle of operation. Anecdotal evidence indicates that some roll transition zone cracks opened up during the hydraulic expansion process (water was observed after the hydraulic expansion step).

The two tubes with quantifiable leakage were R18C44 in 21 steam generator and R16C38 in 22 steam generator. Under a secondary side pressure of 740 psig, R18C44 leaked 2 drops per minute (~1.6E-3 gallons per hour (GPH))and R16C38 leaked at one drop per 3 minutes (~2.6E-4 GPH). During in situ pressure testing at Main Steam Line Break (MSLB) conditions, the minimum measured leak rate was .024 GPH for R18C44 and 0.057 GPH for R16C38. Accurate measurement of low levels of leakage during an in situ pressure test depends on the entire in situ pressure test system being leak tight. Possible sources of system leakage are the relief valve, system connections, and the sealing bladders. Because of these sources of leakage in addition to the degradation in the tube, the final leakage value will be conservative and the final leakage value selected can be the lowest value obtained when several tests are done on the same tube. When in situ pressure tests are done to only Main Steam Line Break pressure, the morphology of the leaking indication is not significantly changed thus allowing repetitive testing at the same conditions or pressures. Tests on the two tubes with measurable leakage, R18C44 and R16C38, were repeated at least once. The leakage value assigned to R18C44 is 0.03 GPH and the leakage value assigned to R16C38 is 0.06 GPH

In response to these discoveries, Modification 95L486 Addendum 1 was implemented which added an additional roll expansion over the original roll transition zone called an "RTZ roll", added additional acceptance criteria for profilometry of the F* reroll and added a post maintenance leak check with the secondary side pressurized. These additional measures are expected to improve steam generator primary to secondary leakage reliability.

Action Plan - Examine Installation Records

Investigation into the possible causes of this leakage has been completed. Evaluation parameters and testing results are provided in Table 1: "Prairie Island Unit 2 Evaluation Parameters for Selected F* Rerolls". No inconsistencies with the installation procedures and process qualification were identified. However, measurements of the profilometry of the F* rerolls indicates an additional screening criteria based on profilometry is appropriate. Several areas were investigated:

1. Evaluation of the previous installation torque traces: A review of the previous field data indicated no torque traces similar to the dry sludge conditions tested in the qualification process. None of the previous field torque traces were as smooth as the wet sludge qualification test samples nor as inconsistent as the dry sludge qualification test samples. There were no distinguishing features between the torque traces of the leaking tubes and a sample of tubes with no leakage. Thus, there appears to be no correlation between the tubes with signs of leakage and the torque trace characteristics. None of the torque traces would have been unacceptable compared to the dry sludge qualification tests.

2. Evaluation of the previous calibration records: The reroll control system was calibrated per the requirements of the installation procedures. No anomalies were identified.

3. Evaluation of Roll Expander Usage and Lubrication: There was not a correlation between roll expander usage and the leaking or seeping F* reroll tubes. The suspect tubes were all done within the first 3 to 105 uses of the maximum allowable of 200 uses of the roll expander. The roll expanders were lubricated as required by procedure.

4. Evaluation of torque values: The torque values for all of the leaking tubes were within the acceptance criteria established during the qualification program and there was no correlation with moist tubes. The torque value attained was within the acceptance band of 100 to 170 in-lbs.

Table 1: Prairie Island Unit 2 Evaluation Parameters for Selected F* Rerolls

						In Situ Results					
Reason	SG	ROW	COL	VOLTS	OEM RTZ CALL	Normal Operating Pressure	MSLB	1995 Applied Torque, in-lbs	LOCATION	LGTH	OEM-F*RR, Diameter Mills
LEAK	21	18	44	31.5	MAI	.0013 to .003 gph	.024 & .027gph	137	1BH - 1.4TO- 1.1	0.3	5.3
LEAK	22	16	38	16.2	MAI	.0004 to .023 gph	.05 to .11 gph	132	1BH - 1.7TO- 1.2	0.5	15.6
Seep	21	18	21	16.8	MAI	0	0	126	1BH - 1.3TO- 0.9	0.4	3.1
Seep	21	11	68	23.7	MAI	0	0	128	1BH - 1.3TO- 1.0	0.3	4.9
Seep	21	7	35	15.0	MAI	0	0	121	1BH - 1.4TO- 1.0	0.4	3.0
Seep	21	11	61	17.9	MAI	0	0	110	1BH - 1.4TO- 1.1	0.3	4.4
Seep	21	1	20	26.3	MAI	0	0	130	1BH - 1.5TO- 0.8	0.7	4.3
Seep	21	5	20	27.2	MAI	0	0	123	1BH - 1.5TO- 0.9	0.6	3.8
Seep	21	9	41	33.2	MAI	0	0	124	1BH - 1.5TO- 0.9	0.6	2.3
Seep	21	10	41	13.5	MAI	0	0	124	1BH - 1.6TO- 1.0	0.6	3.3
Seep	21	3	43	30.5	MAI	.00048 gph[1]	0	120	1BH - 1.6TO- 1.2	0.4	4.9
Seep	22	13	46	38.8	MAI	.00064 gph[1]	0	136	1BH - 1.8TO- 0.9	0.9	8.1
Large Volt	21	23	32	61.4	MAI	0	0	132	1BH - 1.5TO- 0.7	0.8	2.5
Large Volt	21	14	35	62.7	SAI	0	0	117	1BH - 1.5TO- 0.7	0.8	5.6

MAI = multiple axial indication
SAI = single axial indication
1BH is the landmark identifier for the lower roll transtion zone of the F* reroll located 1 inch above the OEM RTZ
[1] only 1 pump stroke, may be less than detectable

Action Plan - Evaluate F* Reroll Bobbin Coil Profilometry Data

All of the F* rerolls installed in 1995 were examined with the bobbin coil and a profilometry standard (In the past, bobbin coil data was used only to demonstrate that the F* reroll was present and located above the OEM hard roll). It was speculated that evaluation of the profilometry data might provide insight into the behavior of the leaking tubes. The parameter chosen for evaluation was the difference in diameter between the average OEM hard roll diameter and the minimum F* reroll diameter. Examples of this diameter measurement difference (in mills) is shown under column "OEM-F*RR" in Table 1. There was one correlation - R16C38 had the largest difference between the OEM hard roll and the F* reroll. Even though there was no other relationship between the suspect tubes and the profilometry data, an acceptance criteria for profilometry based on the difference in diameter between the average OEM hard roll diameter and the minimum F* reroll diameter was added to the installation process at Prairie Island for new F* rerolls. The distribution of the partial data set for the diameter differences of the F* rerolls from the 1995 and 1997 outage is shown below.

Frequency Distribution of Reroll Profilometry				
Diameter Difference	1995		1997	
OEM - Reroll, mills	21 SG	22 SG	21 SG	22SG
1	5	15	3	3
2	25	18	1	4
3	51	11	9	16
4	71	11	30	14
5	60	13	46	17
6	23	10	33	9
7	7	4	11	10
8	8	9	2	11
9	2	5	1	3
10	0	6	1	3
> 10	2	6	6	3
Total	254	108	143	93

Implementation of the profilometry acceptance criteria for both the 1995 and 1997 rerolls required repair of 17 F* rerolls by adding a reroll above the first reroll. Six of the second reroll repairs did not meet the profilometry acceptance criteria and were plugged.

Action Plan - Evaluate Process Parameters against Qualification Report

This evaluation was completed satisfactorily as part of the review of the installation records as discussed above. In addition, the reroll for tube R16C38 was rerolled at the allowable upper torque limit which resulted in an applied torque of 190 in-lbs, which is less than the qualification report upper limit. The difference between the OEM roll and the reroll diameter was reduced from 15.6 mills to 9.2 mills. An in situ pressure test was then conducted. The MSLB leakage for R16C38 was reduced from 0.06 GPH to

0.0019 GPH by the higher torque reroll. This demonstrated that profilometry measurements can, in at least one case, identify the potential for higher leakage rerolls. For several other rerolls at higher torque limits in tubes to be plugged, the higher torques did not increase the diameter significantly, indicating the possible presence of hard sludge in the tubesheet crevice. The procedure requirements for torque limits were not changed.

Action Plan - Determine leak rate at MSLB conditions with in situ pressure tests of selected rerolled tubes

Fourteen tubes with F* rerolls installed in May 1995 were tested in situ. Leakage could only be measured in two of the tubes. For the other twelve tubes tested for at least 20 minutes, the leakage is less than $4.5X10^{-4}$ gallons per hour (GPH). The tubes tested are listed in Table 1.

The in situ pressure test system uses two bladders to isolate the degraded tubing region in order to focus testing on the region of interest. The in situ test probe contained a sufficiently long hydro chamber such that the defects at the OEM RTZ and the F* reroll/hydraulic expansion region were all pressurized to the same value. The sealing bladders are pressurized up to 6000 psig and could have some effect on the sealing properties of the F* reroll. However, the sealing bladders were positioned outside of regions of interest and therefore could not effect the F* reroll seal. The in situ pressure test is done at room temperature and therefore there is no beneficial effect from the increased radial preload at operating temperature due to the higher thermal expansion coefficient of the Alloy 600 tubing compared to the carbon steel tube sheet. Pressures are corrected for temperature effects. The minimum required pressure for the MSLB test was 2816 psig.

Accurate measurement of low levels of leakage during an in situ pressure test depends on the entire in situ pressure test system being leak tight. Sources of leakage are the relief valve, system connections, and the sealing bladders. The pump is a diaphragm pump and is not subject to piston leak by. Higher bladder pressures can assure a reasonably leak tight system. Because of these sources of leakage in addition to the tube degradation, the final leakage value for low levels of leakage will be conservative and the final leakage value selected can be the lowest value obtained when repetitive tests are done on the same tube under the same conditions. When in situ pressure tests are done only to Main Steam Line Break pressure, and no higher, the morphology of the leaking indication is not significantly changed thus allowing repetitive testing at that same pressure. Although particles could conceivably reduce the OEM RTZ crack opening during in situ testing, demineralized water is used for testing and the water is not expected to contribute to plugging of OEM RTZ cracks. In the few cases of multiple tests on the same tube, there was not a decreasing trend which would support plugging of the cracks. Tests on the two tubes with measurable leakage, R18C44 and R16C38 were repeated. Test results for R16C38 were 0.058, 0.072, 0.05, and 0.11 GPH. Test values for R18C44 were 0.024 and 0.027 GPH. The leakage value assigned to R18C44 is 0.03 GPH and the leakage value assigned to R16C38 is 0.06 GPH.

Upon further investigation of R16C38 it was determined that the profilometry measurement identified the F* reroll in R16C38 as an outlier. With the new profilometry acceptance criteria between the OEM hard roll and the F* reroll, R16C38 would have needed to be repaired by an authorized repair or plugged. Therefore, the appropriate conservative leak rate to be assigned to future operating cycles when profilometry acceptance criterion is used is the average leak rate from R18C44 which is 0.03 GPH. For evaluation of the previous operating cycle and current Unit 1 operating cycle, the appropriate leak rate to be assigned is 0.06 GPH since the profilometry acceptance criterion was not applied in the May 1995 (or Unit 1 1996) reroll installation campaign. For tubes which meet the F* criteria based on the OEM hard roll, the qualification report value of 6.87E-4 GPH can be used since the OEM hard roll was made with clean tubing and tubesheet bore holes. (The profilometry data for the six F* rerolls in Unit 1 have been evaluated and all meet the profilometry criteria)

Action Plan - Assessment of Total MSLB Leak Rate for previous PI 2 Cycle 17

The largest number of F* reroll tubes in service in one steam generator was 288 in 21 Steam Generator during the last operating cycle. Multiplying 0.06 GPH per F* reroll tube (F* rerolls are currently only in the hot leg) by 288 rerolls equals 17.3 GPH total leak rate at MSLB conditions. This is an acceptable value compared to the USAR allowable leak rate of 300 GPH (5 GPM) for Main Steam Line Break off-site dose leak rate with an RCS activity level of 1 microcurie/gram dose equivalent I-131 which produces off-site doses equivalent to a small fraction of 10CFR100 dose limits [2,3].

Action Plan - Assessment of Total MSLB Leak Rate for the Current Unit 1 Operating Cycle

The largest number of F* reroll tubes in service in one steam generator in Unit 1 is 3. Multiplying 0.06 GPH per F* reroll by 3 equals 0.18 GPH total leak rate at MSLB conditions. This acceptable value is less than the USAR basis for MSLB of 300 GPH (5 GPM).

Action Plan - Assessment of Total MSLB Leak Rate for Future Operating Cycles

The largest number of F* rerolls that can be in service in one steam generator in the future when utilizing the revised Prairie Island acceptance criteria[4] for F* rerolls is 5 GPM divided by 0.03 GPH per reroll or 10,000 rerolls. Since rerolls can be installed in both hot and cold legs, the maximum number of tubes is 5,000. Since this value is greater than the number of tubes in one steam generator, there is no limit to the number of F* criteria rerolls that can remain service.

Action Plan - Evaluate changes in ET indications due to the Hydraulic Expansion Process

The +Point eddy current data was evaluated for the 12 tubes with indications of moisture. Prior to the hydraulic expansion in 1995, the average voltage of the indications was 2.34 volts. After the hydraulic expansion and the F* reroll, the average

voltage increased to 6.7 volts. The average voltage of these same indications increased to 7.8 volts at the 1997 inspection. Average lengths of these indications increased, likewise, from .26 to .50 inches during the F* reroll process and then to 0.6 inches at the 1997 inspection. The majority of the growth occurred as a result of the F* reroll process. Because the May 1995 F* reroll was applied one inch above the OEM RTZ indications, it is assumed that the major change in the indications was due to the hydraulic expansion step.

Changes to the Reroll Acceptance Criteria and the Reroll Process

Modification 95L486 Addendum 1 added an additional acceptance criteria based on bobbin coil profilometry to insure a minimum F* reroll expansion was attained, added an additional roll expansion over the original roll transition zone, called a "RTZ roll", and added a post maintenance leak check with the secondary side pressurized as additional measures to improve steam generator primary to secondary leakage reliability. All other acceptance criteria remained unchanged including the original torque limits and torque trace requirements for the F* reroll established by ABB Combustion Engineering.

The investigation did not identify reroll process parameters which could positively demonstrate that F* tubes are rerolled into hard packed crevices. It has been determined that the torque trace characteristics under actual steam generator conditions do not readily duplicate the qualification report characteristics. Therefore, it was necessary to identify additional measures which could provide reasonable assurance that potential leakage from an F* reroll is minimized. In particular, as described above, the use of bobbin coil profilometry to identify unusual crevice and or tube conditions is useful. The major change to the reroll acceptance criteria was the addition of specific profilometry acceptance criteria. An acceptance criteria was established for the difference in diameter between the OEM hard roll and the F* reroll. This acceptance criteria resulted in 17 F* rerolls requiring repair and 6 of those reroll repairs requiring plugging. The unacceptable profilometry can be due to hard sludge interference, tube and tubesheet hole dimensional tolerances, or tubing material characteristics.

The purpose of the RTZ roll is to partially seal the roll transition zone stress corrosion cracks (SCC), prevent the hydraulic expansion from opening these known cracks, and reduce the probability of a leak developing past the F* reroll and through the existing roll transition zone cracks. This new RTZ roll is installed prior to the F* reroll and thus has no effect on the F* reroll. The RTZ roll can be added because it is located below the new pressure boundary established by the new additional hard roll installed to meet F* criteria and is not assumed to be there to meet the F* repair criteria. At the start of the 1997 F* reroll installation, a group of twenty tubes was examined by ECT after each step of the new process. The average voltages are shown below.

Pre RTZ Roll	Post RTZ Roll	Post Hydraulic Expansion	Post F* reroll
2.8	1.35	1.72	1.52

It can be seen that the RTZ roll had the desired affect of preventing the large increase in RTZ indications seen during the F* reroll process in 1995.

A post maintenance leak check with the steam generator secondary side filled above the tube bundle and pressurized to greater than 100 psig was added to the F* rerolling process.

In summary, Modification 95L486 Addendum 1 added an additional roll expansion over the original roll transition zone, called an "RTZ roll", additional acceptance criteria for profilometry of the F* reroll and a post maintenance secondary side hydro as additional measures to improve steam generator primary to secondary leakage reliability.

In addition, the acceptable number of F* rerolls in each steam generator was established using the limiting leak rate determined from in situ pressure testing during the Prairie Island 1997 Unit 2 refueling outage. As described above, this value of leakage is small enough such that no limit is applied to the number of F* rerolls.

The secondary side leak check for the new reroll installations was completed on February 18, 1997 with no leakage identified at any of the new F* reroll tubes.

In Situ Pressure Test Leak Rate versus Operational Leak Rate

When the two leaking tubes and the ten seeping tube leakage values at normal operating pressure are added together with a minimum detection level of 4E-4 GPH, the test leakage added up to 0.7 GPD primary to secondary side leakage at normal operational pressures. Although this is less than the measured operational leakage of 2 to 4 GPD, it is within a factor of five which can be considered reasonable. The EPRI PWR Primary to Secondary Leak Guidelines state that leakage below 5 GPD is not in a range that can be accurately monitored and consider leakage less than 5 GPD to be no leakage. Increased monitoring occurs at 5 to 30 GPD and is considered the range at which leakage can begin to be detected and quantified. In addition, there was one leaking explosive plug which would have contributed a small amount of leakage. Therefore, there is reasonable agreement between the in situ test results and the operational measurement of leakage.

Question 1.b:

Estimate the total steam line break leak rate in the limiting steam generator due to bypass leakage around rerolled F* tubes. Discuss the assumptions made regarding the number of tubes rerolled into hard packed crevices with through-wall flaws and the bypass leakage per leaking steam generator tube.

Response:

Development of the leak rate per F* rerolled tube was described in the answers to Question 1a. The assumption was made that all of the tubes were rerolled into hard packed crevices with through wall flaws. This is a conservative assumption since only

two F* rerolls exhibited leakage and 10 exhibited seepage out of a total of 401 F* rerolls under 740 psig secondary side pressure. Prior to improvements of the profilometry acceptance criteria, a leak rate at MSLB conditions of 0.06 GPH is used. This resulted in a conservative estimate of 17.3 GPH for the worst case steam generator compared to a MSLB allowable leakage of 300 GPH. After implementation of the profilometry acceptance criteria, a MSLB leak rate of 0.03 GPH is assumed for all of the F* reroll tubes in service which still allows all of the tubes to have F* rerolls.

Question 1.c:

The ABB/CE report "Series 44 & 51 Design Steam Generator Tube Repair Using A Tube Rerolling Technique ." dated December 1996 (proprietary) states that tubes rerolled into hard packed crevices may have much lower than expected average wall thinning for the rerolled joint. Combustion Engineering Report CEN-620-P demonstrated that tubes rerolled into hard sludge did not move during push testing. However, the assessment does not address the potential strengthening of the tube-to-tubesheet joint caused by the application of a compressive load along the axial direction of the tube. Assess the reduction in the pullout load resistance for F* tubes. If a reduction in the calculated pullout load is greater than that assumed in the F* analysis, discuss the basis for returning tubes to service that are rerolled into hard packed crevices.

Response:

Pull out loads of F* rerolls installed in hard packed crevices have been recently performed. [5] Pull out load with baked on dry sludge occurred at 3470 pounds and in one case, the fixture failed at 6624 pounds force. This pull out load exceeds the pull out force of 2374 pounds which would result from three times the normal operating differential pressure. Based on these tests, there is still sufficient restraining force in a tube with hard packed crevices. It is proposed that leakage could occur in crevices which have a partial packing of the crevice due to channeling through the sludge in the crevice even though in all appearances the F* reroll is acceptable. Based on the in situ tests at Prairie Island, this leakage will still be acceptable.

Excerpts from CE/ABB Test Report on the Pull Testing of Reroll Joints[5]:

4.0 Test Program

A set of reroll samples were prepared in order to cover the range of potential conditions observed in actual steam generators. These conditions include tube hole size, reroll joint torque values and the presence of dry sludge in the crevice region. The test samples and the associated conditions are listed below:

Samples 1 & 2:

Small Hole Diameter High Torque No Sludge In Crevice

Samples 3 & 8:

Large Hole Diameter Low Torque No Sludge In Crevice

Samples 5 & 6:

Nominal Hole Diameter Nominal Torque Dry Sludge In Crevice

The samples were prepared by performing a reroll joint in a steam generator tube sample. The tube samples were prepared from .875" x .050" Inconel 600 tubing and the tubesheet blocks were fabricated from two inch carbon steel bar stock. The tubes were rolled at one end in order to simulate the original hard roll. The two samples with hard sludge had a layer of magnetite slurry applied to the tube outside diameter and block inside diameter prior to hard rolling. These two samples were then placed in an oven at a temperature of ~650°F for eight to ten hours.

The test samples were then placed in a test fixture in order to perform the rerolling operation. The Repair 2000 system was used to perform the proper process steps to the samples. The field reroll procedure was utilized to assure that the proper joint configuration was produced. A roll expander with a 1.25" effective roll length, identical to that used in field applications, was used to make the reroll joints.

5.0 Test Results

The test samples had the original rolled joint machined away and fixtures were welded to the tube and the block in order to allow the pulling of the tube from the tubesheet block. ..... The table below summarizes the test results of this program.

F* PULL TEST DATA

Sample No.	Hole Dia.	Torque Set	Torque Trip	% Wall Reduction	Max. Load
1	.887	110 in-lbs	165.1 in-lbs	5.06	3262 lbs
2	.887	110 in-lbs	165.3 in-lbs	5.80	3358 lbs
3	.893	70 in-lbs	127.4 in-lbs	4.02	3166 lbs
8	.893	60 in-lbs	120.4 in-lbs	3.65	3117 lbs
5	.890	90 in-lbs	145.5 in-lbs	4.06	3470 lbs
6	.890	80 in-lbs	143.7 in-lbs	No Data[1]	6624 lbs

[1] Fitting Failure

All the test samples were pulled to failure. The mode of failure was joint slippage, except for Sample 6, which had a failure of the threaded fitting at the point where it was welded to the tube.

RECONCILIATION OF THE F* LICENSE AMENDMENT REQUEST WITH FIELD EXPERIENCE

The following section discusses the assumptions made in the January 9, 1995 F* License Amendment Request.

The safety evaluation and significant hazards evaluation provided in support of the January 9, 1995 License Amendment Request for the F* repair criterion evaluated the issue of leakage through the F* reroll region. The license amendment request addressed leakage under the F* criterion several times:

In the Background it was stated that:

> **In addition, the proximity of the tubesheet significantly affects the leak behavior of throughwall tube cracks in this region. No significant leakage relative to plant Technical Specification limits is to be expected from application of the F* criterion.**
>
> Evaluation: The operational primary to secondary leakage experienced during the previous Unit 2 operating cycle was 2 to 4 GPD. This was primarily due to two F* rerolls. This value was small compared to both the Technical Specification limit of 1 gpm (1440 GPD) and the Prairie Island administrative limit of 150 GPD.

In the Justification it was stated that:

> **The F* criteria defines a length of undegraded expanded tube in the tubesheet which is sufficient to maintain any potential leakage (resulting from cracks occurring further down in the tubesheet) to well below the Technical Specification limit and Safety Analysis assumptions. The F* criteria were premised on the fact that the tubesheet provides reinforcement of the expanded portion of the tube, provides resistance to tube rupture and collapse, and limits leakage of through wall cracks.**
>
> Evaluation: As discussed in the answer to Question 1a., the leakage value of 0.03 GPH per F* reroll assigned to MSLB conditions results in a total leakage value for both legs of 3388 tubes of 203 GPH which is below the Safety Analysis assumption of 5 GPM (300 GPH). This is conservative since only 12 of 401 tubes were identified with leakage or seepage.

In Safety Evaluation it was stated that:

1. **The proposed change will provide adequate assurance of steam generator tube integrity because the presence of the tubesheet in conjunction with the hardroll process significantly reduces the potential for tube failure and/or leakage within the tubesheet area when compared to the free span portion of the tube. The presence of**

the tubesheet provides for constraint of the tube, and the tubesheet complements the integrity of the tube by minimizing the amount of deformation a tube can undergo beyond its expanded outside diameter. The proximity of the tube and tubesheet, due to the hardroll expansion, limits the amount of primary-to-secondary leakage.

Evaluation: Again, this section states that the F* criterion will limit the amount of primary-to-secondary leakage as was the case with the two leaking F* rerolls identified in Prairie Island Unit 2 steam generators.

2. **An axial length of roll expansion equal to the F* distance at the top of the roll expansion of the tube into the tubesheet provides sufficient structural integrity to preclude pull out of the tube due to pressure effects, even after assuming that the tube has experienced a complete circumferential separation at or below the bottom of the F* distance. This same axial length of roll expansion of the tube into the tubesheet provides a barrier to leakage during all plant conditions for through wall cracking of the tube in the expanded region below F*.**

   Evaluation: The words used here are a "barrier to leakage". There were through wall cracks in the unexpanded region below F* and the F* region did act as a barrier in that it did restrain the amount of leakage through those cracks both for normal operating and accident conditions.

3. **The presence of the elastic preload presents a significant resistance to flow of primary-to-secondary or secondary-to-primary water for degradation which has progressed fully through the thickness of the tube wall. In effect, no leakage would be expected if a sufficient length of hardroll is present. Because of the difficulty in accurately sizing stress corrosion crack indications, the proposed Technical Specifications require that no indications of cracking can be present within the F* distance in tubes to which the F* criterion is applied. This requirement has the effect of preventing the start of a leak path.**

   Evaluation: This section states that no leakage is expected through an F* region. The field experience has demonstrated the contrary. However, sufficient length of hardroll in this case is not defined and the leakage determined by in situ testing will not exceed the design basis value for accident conditions.

4. **The issue of leakage within the F* region up to the top of the roll transition includes the consideration of postulated accident conditions. The issue of leakage within the F* region up to the top of the roll transition includes the consideration of postulated accident conditions. The relationship between the tubesheet region leak rate at most limiting postulated accident (feedline break) conditions relative to that for normal plant operating conditions has been assessed. For the postulated leak source within the roll expansion, increasing the differential pressure on the tube wall increases the driving head for the leak; however, it also increases the tube to tubesheet loading. For an initial location of a leak source a distance greater than F* below the bottom of the roll transition, the feedwater line break pressure differential results in an insignificant leak rate relative to that which could be associated with normal plant operation. This is a result of the increased tube to tubesheet loading associated with the increased differential pressure. Thus, for a circumferential indication within the**

roll expansion that is left in service in accordance with the F* pull out criterion, any leakage under accident conditions would be less than that experienced under normal operating conditions. Therefore, any leakage under accident conditions would be less than the existing Technical Specification leakage limit which is consistent with accident analysis assumptions.

Evaluation: The statement that operational leakage should not increase at accident conditions compared to normal operation is still considered to be true for clean metal to metal interference fits. However, the presence of sludge and scale and the possible resultant channeling of water through the F* reroll prevents increased differential pressure from reducing the leak rate since the tubing material will not flow into and seal the channel regions of the sludge layer. However, the operational experience over the last cycle indicates that operational leakage from F* rerolls does not challenge the Technical Specification Limit of 1 gpm. The leakage through the two dripping tubes and the seeping tubes was nearly constant throughout the 570 day cycle even though the leakage path was active immediately following startup. The seepage of moisture through 10 tubes occurred after 2 days at about 740 psig secondary side pressure and these tubes did not leak during in situ testing. A conservative value of 0.023 GPH can be assigned to operational leakage per F* reroll based on data from R16C38. This value is less than the accident leakage value but more than 20% of the accident leakage value so that the plant would be shutdown for repairs prior to reaching leakage which would exceed the accident analysis assumptions. There is additional conservatism here, since only a small fraction of the F* rerolls appear to have leakage potentially caused by sludge or hard scale deposits.

In the Determination of Significant Hazards Considerations it is stated that:

1. **The existing Technical Specification leakage rate requirements and accident analysis assumptions remain unchanged in the unlikely event that significant leakage from this region does occur. As noted above, tube rupture and pullout is not expected for tubes using the F* criterion. Any leakage out of the tube from within the tubesheet at any elevation in the tubesheet is fully bounded by the existing steam generator tube rupture analysis included in the Prairie Island Plant USAR.**

   Evaluation: As discussed in the answers to Question 1a, the leakage experienced at Prairie Island, although more than expected from the ABB-CE topical reports, is still bounded by the leakage assumptions for accident conditions. In particular, the leakage per F* reroll, assuming all F* rerolls are in the presence of hard sludge, still allows all tubes to be repaired with F* rerolls.

2. **Leakage testing of roll expanded tubes indicates that for roll lengths approximately equal to the F* distance, any postulated faulted condition primary to secondary leakage from F* tubes would be insignificant.**

   Evaluation: Although the leakage may no longer be insignificant, the leakage is still bounded by the licensing basis assumptions.

3. **Tube bundle leaktightness will be maintained such that any postulated accident leakage from F* tubes will be negligible with regard to offsite doses.**

   Evaluation: If all tubes contain leaking F* rerolls in each leg, the leakage is postulated to be 3.4 GPM which is less than the accident analysis assumption of 5 GPM and would not result in exceeding a small fraction of 10CFR100 dose limits.

4. **The leak testing acceptance criteria are based on the primary to secondary leakage limit in the Technical Specifications and the leakage assumptions used in the USAR accident analyses.**

   Evaluation: If all tubes contain leaking F* rerolls in each leg, the leakage is postulated to be 3.4 GPM which is less than the accident analysis assumption of 5 GPM and would not result in exceeding a small fraction of 10CFR100 dose limits

Summary of Evaluation of the Prairie Island License Amendment Request:

The preponderance of evidence shows that the safety evaluation was based on the premise that the proposed F* distance would not provide an absolutely a leak tight repair, even though there were expectations that the repair would approach leak tightness. The evaluation did not assume that use of the proposed F* distance would provide a leak tight repair, rather it assumed that the use of the F* repair technique would provide a joint which would limit the amount of primary to secondary leakage to an acceptable level. The in situ test results support the assumption that all tubes can have F* rerolls without exceeding the off site dose requirements for accident conditions.

The significant hazards consideration evaluation concluded that any leakage resulting from the use of the F* repair technique would not involve any significant hazards considerations because:

- The existing Technical Specification leakage rate requirements and accident analysis assumptions remain unchanged in the unlikely event that significant leakage from this region does occur.

- Any leakage out of the tube from within the tubesheet at any elevation in the tubesheet is fully bounded by the existing steam generator tube rupture analysis included in the Prairie Island Plant USAR. For plants with partial depth roll expansion like Prairie Island, a postulated tube separation within the tube near the top of the roll expansion (with subsequent limited tube axial displacement) would not be expected to result in coolant release rates equal to those assumed in the

USAR for a steam generator tube rupture event due to the limited gap between the tube and tubesheet.

- Leakage testing of roll expanded tubes indicates that for roll lengths approximately equal to the F* distance, any postulated faulted condition primary to secondary leakage from F* tubes would be acceptable.

- Tube bundle leak tightness will be maintained such that any postulated accident leakage from F* tubes will be negligible with regard to offsite doses.

- The F* distance has been verified by testing to be greater than the length of roll expansion required to preclude both tube pullout and significant leakage during normal and postulated accident conditions.

The results of the steam generator leak test and eddy current examination results obtained during the current Unit 2 refueling outage have been assessed against the leakage assessments in the January 9, 1995 License Amendment Request and the conclusions of the associated safety evaluation and significant hazards evaluation. The leakage assessments in the subject license amendment request and the conclusions of the safety evaluation and significant hazards evaluation are supported by the test results, except if all the steam generator tubes are assumed to have been repaired using the F* technique, the total leakage under main steamline break conditions could be greater than that associated with normal plant operation and could exceed the Technical Specification limit for steam generator leakage (1 gpm), but the accident dose assumptions would still not be exceeded.

Therefore, the measured leakage is bounded by the leakage assessments in the F* license amendment request. The results of the Unit 2 steam generator tube leak testing and eddy current examinations do not change the conclusions of the F* license amendment request safety evaluation and significant hazards evaluation.

RECONCILIATION OF THE NRC F* SAFETY EVALUATION WITH FIELD EXPERIENCE

The following section discusses the issues pertinent to leakage in the NRC Safety Evaluation Report for the May 15, 1995 F* License Amendment.

The license amendment approving the proposed use of the F* steam generator tube repair criteria was approved by the NRC on May 15, 1995. The NRC safety evaluation associated with that license amendment supported the conclusions of the safety evaluation and significant hazards evaluation from the January 9, 1995 F* license amendment request. In response to the results of the Unit 2 steam generator tube leak testing and eddy current examinations, the NRC safety evaluation for the approval of F* for Prairie Island was assessed to determine if the conclusions of the safety evaluation remain bounding. Statements from the NRC safety evaluation which were assessed to determine if they remain bounding as a result of the Unit 2 steam generator tube in situ

leak testing and eddy current examinations are listed below along with our evaluation. The remaining portions of the NRC safety evaluation clearly bounded the results of the Unit 2 in situ leak testing and eddy current examinations.

In the NRC Safety Evaluation it is stated that:

1. **The presence of the elastic preload presents a significant resistance to flow of primary-to-secondary or secondary-to-primary water for degradation which has progressed fully through the thickness of the tube wall. In effect, no leakage would be expected if a sufficient length of hardroll is present.**

   Evaluation: As evaluated above, the leakage at MSLB conditions determined by in situ pressure testing will not exceed the assumptions for accident conditions.

2. **The issue of leakage within the F* region up to the top of the roll transition includes the consideration of postulated accident conditions. The relationship between the tubesheet region leak rate at most limiting postulated accident (feed line break) conditions relative to that for normal plant operating conditions has been assessed. For the postulated leak source within the roll expansion, increasing the differential pressure on the tube wall increases the driving head for the leak; however, it also increases the tube to tubesheet loading. For an initial location of a leak source a distance greater than F* below the bottom of the roll transition, the feedwater line break pressure differential results in an insignificant leak rate relative to that which could be associated with normal plant operation. This is a result of the increased tube to tubesheet loading associated with the increased differential pressure. Thus, for a circumferential indication within the roll expansion that is left in service in accordance with the F* pull-out criterion, any leakage under accident conditions would be less than that experienced under normal operating conditions. Therefore, any leakage under accident conditions would be less than the existing TS leakage limit which is consistent with the accident analysis assumption.**

   Evaluation: As evaluated above, the operational leakage will be less than accident leakage for some tubes. However, this leakage is more than 20% of the accident leakage value so that the plant would be shutdown for repairs prior to reaching leakage which would exceed the accident analysis assumptions.

3. **In its letters dated January 9, and February 7, 1995, the licensee stated that it will implement rerolled tubesheet joint expansions to obtain new leak tight rerolled joints for tube repair.**

   Evaluation: NSP did not use these exact words, but rather committed to not leaving reroll torque traces in service representative of hard sludge conditions. This commitment has been met to the capability of the acceptance criteria available. However, it is now known that field conditions may result in leak limiting rerolled joints in some cases. Since, the basic premises for the F* criterion is that it is a leak limiting joint, NSP will evaluate changing this commitment.

4. **All tests provided sufficient tube pull out restraint, however, the baked on sludge resulted in minor leakage. Because of this minor leakage, tubes with reroll torque traces representative of hard sludge will not be left in service. Evaluation of the torque trace provides the basis for acceptance or rejection of the new roll region.**

   Evaluation: A review of the previous field data found no torque traces similar to the dry sludge conditions tested in the qualification process. This commitment will remain in place. However, both torque trace evaluation and profilometry measurements will insure all rerolls are leak limiting. Since the basic premise of the F* criterion is leak limiting, the reroll process still meets the requirements to not exceed accident condition leakage limits.

5. **The staff asked the licensee to address the ramifications of having more than one alternate repair criterion that allows leakage. The total leakage should continue to be within the allowed limits under accident conditions. In its March 15, 1995, letter, the licensee addressed the maximum postulated accident leakage from cracks allowed to remain in service under the F*, L* and other criteria, such as the interim repair criteria. The licensee has revised the bases for 4.12 to incorporate the following statement:**

   > **When more than one Alternate Repair Criteria are used, the summation of leakage from all the tubes left in service by all repair criteria must be less than the allowable leakage for the most limiting of those Alternate Repair Criteria.**

   The staff finds the licensee will ensure leakage limits are not exceeded with its proposed statement.

   Evaluation: This provides substantiation that the F* criterion is a leak limiting criterion. Evaluation of the in situ test results confirms that leakage limits are not exceeded.

REVIEW OF TECHNICAL SPECIFICATION BASES

The bases for Technical Specification 3.1.B, Steam Generator Pressure/Temperature Limits, and 3.1.C.2.e, Steam Generator Tube Leakage were reviewed. The addition of acceptance criteria based on profilometry provide reasonable assurance that F* rerolls will limit leakage to a small amount. The assignment of a higher leakage value per F* reroll than defined in the reroll process qualification report is still within the limits of the use of the F* criteria. Evaluating this site specific limiting leak rate for the F* rerolls is in accordance with the basis to Technical Specification 4.12 and insures the requirements of the license amendment request are met.

The basis for Technical Specification 4.12 states that "When more than one Alternate Repair Criteria are used, the summation of leakage from all tubes left in service by all repair criteria must be less than the allowable leakage for the most limiting of those Alternate Repair Criteria." Previously, the expected MSLB leakage from F* tubes of 6.87E-4 GPH would have resulted in a 2.3 GPH leak rate if 3388 tubes contained

leaking F* rerolls. The new MSLB leakage value of 0.03 GPH per F* reroll assigned by in situ pressure testing results in a 102 GPH leak rate if 3388 tubes contained leaking F* rerolls. This value is less than the allowable 300 GPH (5 GPM) for MSLB.

CONCLUSIONS

NSP has evaluated the leakage identified with two F* reroll repairs in the Prairie Island Unit 2 steam generators and has concluded that:

1. Structural and leakage integrity is maintained during normal and accident conditions,

2. The leakage identified in these tubes is bounded by the Prairie Island Technical Specifications and the conclusions of the safety evaluation and significant hazards evaluation in the January 9, 1995 F* License Amendment Request,

3. The NRC Safety Evaluation included with the May 15, 1995 F* License Amendment supports the premise that the F* repair criterion is a leak limiting criterion,

4. Prairie Island can operate safety utilizing the F* reroll repair process, and

5. Improvements to the reroll process were made to minimize the expected leakage from F* reroll joints.

REFERENCES

[1] ABB Combustion Engineering report CEN-620-P Revision 00, March 1995, "Series 44 & 51 Design Steam Generator Tube Repair Using a Tube Re-rolling Technique"

[2] DESIGN BASES DOCUMENT, "ACCIDENT ANALYSIS", DBD-TOP-01, Rev. 1, Sections 3.4.4 and 5.2.1

[3] FSAR Section 14.2.5, "Rupture of a Steam Pipe", page 14.2-34d, amendment 33, 4-9-73

[4] Prairie Island Modification 95L486 Addendum 1: "Add A Hardroll Over The Original Roll Transition Zone To The Additional Roll Expansion Repair Process for Steam Generator Tubes and Add Additional Acceptance Criteria for F* Rerolls"

[5] ABB Combustion Engineering Report 97-TR-FSW-009 Revision 00, "Test Report on the Pull Testing of Reroll Joints in Steam Generator Tubes", dated 2-15-97